Nitrogen content and indices of selected crops grown in the San Luis Valley of south central Colorado and their use in simulating crop N uptake and soil N transformations

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Introduction:

Irrigated Agriculture in the Valley

The San Luis Valley, with an average elevation of 7,700 ft, is a high altitude intermountain desert valley located in south central Colorado with the Sangre de Cristo mountains to the east and the San Juan mountains to the west. The valley is about 105 miles long and 20 to 50 miles wide. With an average annual precipitation of 7.1 inches in Alamosa County, agriculture requires irrigation to maintain viable productivity. Prior to 1880, irrigated acreage was small but between 1880 to 1890, an intensive network of canals was constructed. By 1904, all streams entering the valley were diverted for irrigation. Intensive development of groundwater for irrigation began during the 1950's with the introduction of high capacity pumps. To improve the efficiency of groundwater use, sprinkle irrigation began to be used extensively in the 1970's, and increased from 262 wells in 1973 to more than 2,000 by 1996.

The importance of this intermountain desert valley for Colorado's agriculture, is reflected in the area and yield of the predominant crops grown in the valley which includes: potato (74,000 acres; 350 Cwt/acre); spring wheat (30,500 acres; 96 Bu/acre); barley (58,000 acres; 95 Bu/acre); oat (18,000 acres; 78 Bu/acre), alfalfa hay (135,000 acres; 3.5 ton/acre) and other hay (65,000 acres; 2.1 ton/acre) as reported by USDA and Colorado Agricultural Statistics (1994). The San Luis Valley in 1993 produced 91% of the potato, 83% of the spring wheat, 76% of the barley, 35% of the oat and 14% of the hay produced in Colorado. Production of lettuce, carrot and spinach represents an important and viable crop production base of about 7,600 acres. Also, in 1995, there were 6,000 acres dedicated to the production of canola.

Drinking-water with high nitrate (NO_3) concentrations poses known health risks to humans and livestock. Water supplies that contain more than 10 ppm of NO_3-N exceed the national drinking water standard. The most susceptible to the NO_3 health risk of methemoglobinemia are infants and children under six months of age. A recent study found well water NO_3-N concentrations as high as 80 ppm, north of the town of Center in the San Luis Valley. The combination of use of N fertilizer, a high water table and sandy soils are factors that contribute to this elevated concentration of NO_3-N in groundwater. There is a growing concern about the movement of NO_3-N out of the root zone as it possibly contributes to NO_3-N concentrations in groundwater.

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Use of N and C content in plants to simulate crop N uptake and N transformations in the root zone

In response to these concerns of higher NO_3-N concentrations in the groundwater, the USDA Working Group for Water Quality in Cooperation with Colorado State University Cooperative Extension (CSUCE) has established the San Luis Valley Water Quality Demonstration Project (SLVWQDP) to promote the use of best management practices and to minimize agricultural non-point source pollution of water resources in the Valley. The USDA-ARS and USDA-NRCS are using NLEAP (Nitrate Leaching and Economic Analysis Package), a computer software package, capable of providing a rapid and efficient evaluation of farm management practices on soil N and water budgets and their impact on NO_3-N movement out of the root zone. This computer simulation model is capable of generating computer outputs to identify areas where irrigation water and N management practices create NO_3-N leaching problems. By identifying the problem, the development of management alternatives that reduce the amount of NO_3-N leaching and increase water- and N-use efficiency can be implemented. NLEAP is being shared by NRCS, SLVWQDP and CSUCE with project cooperators to help focus on management strategies that can reduce NO_3-N movement out of the root zone. Agricultural management practices and soil, crop, and irrigation data have been collected on 25 cooperating farms to evaluate the status of current N management practices on soil N transformations and their impact on residual soil NO_3-N available to leach. When completed, a unique data set, consisting of about 80 site-years of information will be used to test NLEAP across different cropping systems.

The NLEAP model estimates the impact of water and N management practices on the movement of NO_3-N out of the root zone by accounting for all N and water inputs and outputs to the root zone. The model is set up in a way that it can be used to account for N and water budgets in different cropping systems. In accounting for these water and N budgets, the model simulates total N uptake by the crop, which is one of the important N sinks. To simulate crop N uptake, the model uses a regional configuration file that contains the crop N uptake index (NUI), which is a measurement of N uptake per unit of yield. The user supplies the crop planting and harvesting dates, N- and water- management inputs and timing, soil and climate information, and the expected yield. NLEAP will then simulate N uptake during the growing season.

The carbon to nitrogen (C/N) ratio of the unharvested portion of the crop is another value used in the NLEAP model. The C/N ratio of the unharvested crop residues returned to the soil affects soil N transformations in the root zone. With high C/N values, immobilization of NH_4-N can initially occur. With low C/N ratios, NH_4-N is mineralized from the crop-residue and then nitrified to NO_3-N which may be taken up by the following crop. This is important when winter cover crops are used to scavenge soil NO_3-N from the lower depths of the soil profile. The cover crop is then later returned to the soil to supply N to the root zone of the following crop. San Luis Valley farmers are using winter wheat or winter rye to reduce soil erosion, scavenge soil-N and to return organic carbon to the soil. By early spring, the fields are plowed and the plant-residue is incorporated into the soil before carrot, lettuce and potato are planted. Data on the effect of planting date, residual soil NO_3-N on crop N content, C/N ratio, and NUI of winter cover crops for 10 site-years are presented.

The purpose of this publication is to present our initial findings for crop N content, C/N ratios, and NUI, for the crops studied. These values are being used in the development of a local crop NLEAP file for the San Luis Valley. When completed, this local region.idx file will be

used in the NLEAP model to simulate crop N uptake and soil N transformations in the root zone for these crops.

Approach

Harvesting procedures and N analyses

From 1993 to 1996 plots were established at a series of farmer's fields where samples from different plant parts were collected (Tables 1 and 2). Plots were sampled over two or three years. At other farmer's fields, plant samples for the various crops grown were collected at random from the field. The sum of the total crop N content in all plant parts and yields were used to estimate NUI which is a measurement of crop N uptake per unit of yield. We calculated NUI with equation one. Yield is the harvested crop production for the growing season.

$$NUI = \frac{\text{Crop N uptake for the growing season (lbs N/acre)}}{\text{Yield for the growing season (Tons or Bushels/acre)}} \quad (1)$$

All NUI's in Table 3 were adjusted for the water content of the harvested unit and weight per unit of yield used in the NLEAP model (Table 3). Plant material was analyzed for total N and C using a Carlo Erba automated C/N analyzer. Statistical analyses were performed using the SAS software for data analysis for microcomputers.

Summary

Results from the last three years are presented in Tables 2 and 3. The mean crop N content (%), and C/N ratios for the harvested and unharvested plant parts, for small grains, potato, vegetables, and winter cover crops are presented in Table 2. The mean NUI for these crops and varieties are presented in Table 3. This data set of plant parameters will be used, with the respective, soil chemical and physical information, irrigation practices, N management practices, and amount of N in the irrigation water, as inputs into the NLEAP model to simulate crop N uptake and soil N transformations in the root zone. Local climatological data will also be used for these computer simulations. The NLEAP model will use these simulations of the crop N uptake and soil N transformations to calculate N and water budgets for each cropping system. NLEAP simulations include other soil transformations and dynamics such as ammonia volatilization, denitrification, NO_3-N leaching and others. The simulation provides a summary of the soil inorganic NO_3-N content in the soil profile which will be compared with the measured values at each farm. Preliminary NLEAP simulations show a significant potential to account for the effect of management on N and water budgets and the dynamics of the soil N transformations in the root zone of these high altitude intermountain cropping systems. Preliminary results also show that winter cover crops conserve N, reduce soil erosion (data not shown), return organic C and N to the surface soil and protect soil and water quality.

Table 1. Selected crops grown in the San Luis Valley.

Crop description or common name	Scientific name
Alfalfa	*Medicago sativa* L.
Barley	*Hordeum vulgare* L.
Canola	*Brassica napus* L.
Carrot	*Daucus carota*
Lettuce	*Lactuca sativa* L.
Oat	*Avena sativa* L.
Potato	*Solanum tuberosum* L.
Rye	*Secale cereale* L.
Spinach	*Spinacia oleracea* L.
Wheat	*Triticum aestivum* L.

Table 2a. Mean crop Nitrogen content (%N) and Carbon:Nitrogen ratio (C/N) ± 1 Standard Deviation (Std) for selected small grains grown in the San Luis Valley. Values are expressed on a dry weight basis.

Crop[1]	Variety[2]	Part[3]	% N Mean Std	C/N Mean Std
Barley	Moravian 14 (*16*)	Grain	1.63 ± 0.09	26.5 ± 1.3
		Stalk & Chaff	0.53 ± 0.07	78.4 ± 10.0
	Moravian III (*12*)	Grain	1.74 ± 0.17	
		Stalk & Chaff	0.50 ± 0.07	
	Triumph (*3*)	Grain	1.24 ± 0.02	33.8 ± 0.4
		Stalk & Chaff	0.53 ± 0.03	75.9 ± 3.2
Canola	IMC 129 (*9*)	Grain	3.58 ± 0.16	16.5 ± 0.8
		Stalk & Chaff	0.96 ± 0.34	56.3 ± 13.9
		Root	0.50 ± 0.09	83.5 ± 20.4
Oat	Monida (*2*)	Grain	1.70	
		Stalk & Chaff	0.41	
Oat *(Hay)*	Russell (3) *(High N)*	Hay	1.41 ± 0.27	43.4 ± 0.3
Winter wheat	Tomahawk (*8*)	Grain	2.24 ± 0.08	19.3 ± 0.6
		Stalk & Chaff	0.66 ± 0.10	61.9 ± 9.7

[1] For Crop, high soil NO_3-N content means that residual soil NO_3-N was > 600 lb N/acre for the top 5 ft.
[2] Numbers in parenthesis indicate number of observations; Low indicates low N inputs.
[3] Stalk & Chaff means all aboveground crop biomass minus Grain; Hay, Shoot, Top, Head, and Stem & Leaf means all aboveground crop biomass; Plants means all aboveground and belowground crop biomass;

Note: Applied to tables 2*b*, *c*, and *d*.

Table 2b. Mean crop Nitrogen content (%N) and Carbon:Nitrogen ratio (C/N) ± 1 Standard Deviation (Std) for selected vegetables grown in the San Luis Valley. Values are expressed on a dry weight basis.

Crop[1]	Variety[2]	Part[3]	% N Mean Std	C/N Mean Std
Carrot	Caropak (*7*)	Top	1.54 ± 0.25	24.1 ± 1.9
		Root	0.89 ± 0.04	43.4 ± 3.0
	Flame (*3*)	Top	1.84 ± 0.06	20.9 ± 0.7
		Root	1.04 ± 0.02	38.4 ± 0.5
Lettuce *(Head)*	821 (*3*)	Head	3.34 ± 0.03	
	Fallgreen (*41*)	Head	3.43 ± 0.47	10.7 ± 1.4
	Summertime (*7*)	Head	3.30 ± 0.10	11.2 ± 0.4
Spinach	Tyee (*6*)	Top	4.94 ± 0.18	7.1 ± 0.4
		Root	4.60	

Table 2c. Mean crop Nitrogen content (%N) and Carbon:Nitrogen ratio (C/N) ± 1 Standard Deviation (Std) for selected winter cover crops grown in the San Luis Valley. Values are expressed on a dry weight basis.

Crop[1]	Variety[2]	Part[3]	% N Mean Std	C/N Mean Std
Winter rye *(Planted early in fall)*	Common (*8*)	Shoot	2.35 ± 0.29	16.2 ± 2.1
Winter rye *(Planted early in fall - High soil NO_3-N)*	Common (*4*)	Shoot	4.82 ± 0.21	8.7 ± 0.3
		Crown	4.00 ± 0.16	9.3 ± 0.2
Winter rye *(Planted late in fall)*	Common (*12*)	Shoot	3.47 ± 0.61	11.3 ± 1.1
		Plant	4.36 ± 0.29	9.7 ± 0.6
Winter wheat *(Grazed cover crop planted early in fall)*	Tomahawk (*4*)	Plant	3.33 ± 0.10	11.8 ± 0.3
Winter wheat *(Grazed cover crop planted late in fall)*	Tomahawk (*4*)	Plant	3.92 ± 0.12	10.9 ± 0.2

Table 2d. Mean crop content (%N) and Carbon:Nitrogen ratio (C/N) ± 1 Standard Deviation (Std) for selected potato varieties grown in the San Luis Valley. Values are expressed on a dry weight basis.

Crop[1]	Variety[2]	Part[3]	% N Mean Std	C/N Mean Std
Potato	Burbank (*12*)	Stem & Leaf	2.11 ± 0.18	14.4 ± 0.6
		Tuber	1.88 ± 0.07	22.3 ± 0.9
	Centennial (*22*)	Stem & Leaf	2.87 ± 0.68	12.0 ± 2.0
		Tuber	1.53 ± 0.19	27.0 ± 3.5
		Root	1.64 ± 0.25	20.3 ± 2.0
	Century (*8*)	Stem & Leaf	2.31 ± 0.49	13.1 ± 0.9
		Tuber	1.28 ± 0.12	29.0 ± 1.1
		Root	1.13 ± 0.12	26.7 ± 2.7
	Frontier (*9*) *(Low N)*	Stem & Leaf	2.38 ± 0.27	
		Tuber	1.33 ± 0.14	
	Nugget (*15*)	Stem & Leaf	2.46 ± 0.87	17.5 ± 11.1
		Tuber	1.68 ± 0.34	25.4 ± 6.8
		Root	1.59 ± 0.14	18.4 ± 1.3
	Nugget (*9*) *(Low N)*	Stem & Leaf	2.01 ± 0.23	
		Tuber	1.13 ± 0.05	
	Norkota (*8*)	Stem & Leaf	1.35 ± 0.12	17.5 ± 1.2
		Tuber	1.91 ± 0.06	21.4 ± 0.7
	Sangre (*3*)	Stem & Leaf	1.30 ± 0.10	31.2 ± 2.4
		Tuber	1.88 ± 0.15	17.7 ± 1.5
		Root	0.94 ± 0.11	36.1 ± 6.3

Table 3a. Mean Nitrogen crop indices (NUI) for whole plant (aboveground and underground parts) ± 1 Standard Deviation (Std) for selected small grains grown in the San Luis Valley. The NUI values are adjusted for water content and weights of the yield unit.

Crop[1]	Variety[2]	Yield Unit[3]	Lbs/Yield Unit[4]	Water Content[5] %	NUI[6] Mean Std
Barley	Moravian 14 (*16*)	Bushel	48	12	1.00 ± 0.07
	Moravian III (*12*)	Bushel	48	12	1.17 ± 0.12
	Triumph (*3*)	Bushel	48	12	0.78 ± 0.03
Canola	IMC 129 (*9*)	Bushel	50	12	3.03 ± 0.57
Oat	Monida (*2*)	Bushel	32	12	0.73 ± 0.02
Oat *(Hay)*	Russell *(3)* *(High N)*	Tons	2000	12	26.19 ± 4.92
Winter wheat	Tomahawk (*8*)	Bushel	60	12	1.76 ± 0.09

1 For Crop, high soil NO_3-N content means that residual soil NO_3-N was > 600 lb N/acre for the top 5 ft.

2 Numbers in parenthesis indicate number of observations.

3 Yield unit used for NLEAP.

4 Amount of pounds per yield unit used for NLEAP.

5 Water content for the harvested portion used for NLEAP.

6 NUI values used in the NLEAP model. Values were adjusted using the lbs/yield unit and water content of the harvested unit. When the belowground crop parts were missing, we assumed a ratio of belowground N/ total N of: 0.1 in crowns and roots for barley and winter wheat; 0.01 in lettuce; 0.05 in oats; 0.25 in winter rye; 0.05 in spinach; 0.05 in canola, and 0.018 in potato.

Note: Applied to tables 3*b*, *c*, and *d*.

Table 3b. Mean Nitrogen crop indices (NUI) for whole plant (aboveground and underground parts) ± 1 Standard Deviation (Std) for selected vegetables grown in the San Luis Valley. The NUI values are adjusted for water content and weights of the yield unit.

Crop[1]	Variety[2]	Yield Unit[3]	Lbs/Yield Unit[4]	Water Content[5] %	NUI[6] Mean Std
Carrot	Caropak (*7*)	Tons	2000	90	2.97 ± 0.27
	Flame (*3*)	Tons	2000	90	3.72 ± 0.08
Lettuce *(Head)*	Fallgreen (*41*)	Tons	2000	94	4.16 ± 0.56
	Summertime (*7*)	Tons	2000	94	4.01 ± 0.12
	821 (*3*)	Tons	2000	94	4.05 ± 0.03
Spinach	Tyee (*6*)	Tons	2000	90	10.39 ± 0.40

Table 3c. Mean Nitrogen crop indices (NUI) for whole plant (aboveground and underground parts) ± 1 Standard Deviation (Std) for selected potato varieties grown in the San Luis Valley. The NUI values are adjusted for water content and weights of the yield unit.

Crop[1]	Variety[2]	Yield Unit[3]	Lbs/Yield Unit[4]	Water Content[5] %	NUI[6] Mean Std
Potato	Burbank (*12*)	Tons	2000	80	10.03 ± 0.70
	Centennial (*22*)	Tons	2000	80	9.30 ± 1.66
	Century (*8*)	Tons	2000	80	6.88 ± 1.24
	Frontier (*9*) (*Low N*)	Tons	2000	80	6.92 ± 0.85
	Nugget (*15*)	Tons	2000	80	9.30 ± 2.22
	Nugget (*9*) (*LowN*)	Tons	2000	80	6.25 ± 0.69
	Norkota (*8*)	Tons	2000	80	8.54 ± 0.34
	Sangre (*3*)	Tons	2000	80	9.45 ± 0.89

Table 3d. Mean Nitrogen crop indices (NUI) for whole plant (aboveground and underground parts) ± 1 Standard Deviation (Std) for selected winter cover crops grown in the San Luis Valley. The NUI values are adjusted for water content and weights of the yield unit.

Crop[1]	Variety[2]	Yield Unit[3]	Lbs/Yield Unit[4]	Water Content[5] %	NUI[6] Mean Std
Winter rye (*Planted early in fall*)	Common (*8*)	Tons	2000	50	18.79 ± 2.28
Winter rye (*Planted early in Fall- High soil NO_3-N)*	Common (*4*)	Tons	2000	50	40.45 ± 3.96
Winter rye (*Planted late in fall)*	Common (*12*)	Tons	2000	70	27.12 ± 3.87
Winter wheat (Grazed cover crop p*lanted early in fall)*	Tomahawk (*4*)	Tons	2000	50	20.00 ± 0.63
Winter wheat (Grazed cover crop p*lanted late in fall)*	Tomahawk (*4*)	Tons	2000	70	23.49 ± 0.71